On-Road Bicycle Facilities and Cyclist Injury in Bicycle-Motor Vehicle Crashes in Chicago

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THESIS

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LIST OF ABBREVIATIONS

AIS	Abbreviated Injury Scale
ACS	American Community Survey
AOR	Adjusted Odds Ratio
CDOT	Chicago Department of Transportation
CTA	Chicago Transit Authority
FARS	Fatality Analysis Reporting System
GIS	Geographic Information Systems
IDOT	Illinois Department of Transportation
MV	Motor Vehicle
NHTS	National Household Travel Survey
NHTSA	National Highway Transportation Safety Administration
OR	Odds Ratio
MSL	Marked Shared Lane
WISQARS	Web-based Injury Statistics Query and Reporting System

SUMMARY

This cross-sectional study examined road crashes between motor vehicles (MV) and bicycles from 2008–2010 in the city of Chicago using traffic crash report data from the Illinois Department of Transportation (IDOT). The primary dichotomous outcome was an incapacitating or fatal injury to the pedal-cyclist. Geographic Information Systems (GIS) shape files containing on-road bicycle facilities (i.e., designated bike lanes, marked shared lanes (MSL), or signed recommended bike routes) were obtained from the city of Chicago and ArcGIS was used to determine presence of a bike facility or bus stop near each crash point. Crashes at intersections and non-intersection points were analyzed separately.

Nearly three-fifths of the crashes over the three years of this study were intersection-related but there was no difference in severe and fatal injury prevalence between intersection and non-intersection crashes. There were significantly more intersection crashes on or near recommended bike routes, while greater percentages of non-intersection crashes occurred near bike lanes and marked shared lanes. There were no statistically significant bivariate associations between the presence of any bicycle facility or bus stop and severe cyclist injury. In the multivariable models, only presence of a recommended bike route was significantly negatively associated with severe cyclist injury for intersection crashes, and a designated bike lane was marginally negatively associated with severe injury in non-intersection crashes. Neither bike lanes near intersection crashes nor recommended bike routes at non-intersection crash points were associated with the injury outcome. There was no relationship between presence of MSLs (also called “sharrows”) and severe and fatal cyclist injury at either crash location.

Relationships between other important variables such as the cyclist’s age being 70 or older (non-intersection crashes), the motor vehicle being a truck (intersection crashes), motor vehicle driver intoxication/impairment (both crash locations) and the severe injury outcome were positive, statistically

SUMMARY (continued)

significant, and consistent with previous studies. Results from this study suggest that signed recommended bike routes and designated bike lanes may be associated with reduced severe or fatal injury occurrence to cyclists in crashes with motor vehicles at intersection and non-intersection locations, respectively. Given important study limitations, including use of police report crash data, GIS methods, potential misclassification on both exposure and outcome, and missing data, these results should be interpreted with caution.

1. INTRODUCTION

1.1 Background

Bicycling behavior has been the subject of research, policy, and advocacy interest in recent years due to concerns over the contribution of MV emissions to climate change and rising obesity rates and given the concomitant expansion of utilitarian commuting by bicycle. Increasing the rate of bicycling is understood to have positive impacts on public health through two specific mechanisms: (1) reduction of greenhouse gas emissions as cycling is employed as an alternative to fossil fuel-dependent modes of travel, and (2) increasing moderate-intensity physical activity. It is projected that increases in trips by bicycle could have substantial health and economic benefits due to decreased pollution from automobile exhaust in urban areas. One comparative risk assessment study of two large global cities estimated that increased active travel (i.e., walking or biking) would have a greater impact in terms of disability-adjusted life years than a switch to lower-emissions MVs alone.[1] Another study looked at the effect of reduced automobile usage for short trips in urbanized areas on air quality and mortality across 11 metropolitan areas in the Midwest region of the United States.[2] The authors ran a simulation in which 50% of short trips were made by bicycle, and found a possible reduction of 1300 deaths, given reduced pollution and increased physical activity, and $3.8 billion in savings related to health care costs and associated mortality.

The health benefits from the exercise cycling provides are more thoroughly documented, with studies going back over 20 years.[3] A review published in 2011 of 16 studies found that nearly all the studies identified a health benefit from cycling, and both cross-sectional and longitudinal designs showed improved cardiorespiratory fitness in youths.[4] Most of the prospective cohort studies observed a reduction in mortality due to cardiovascular disease. Findings from a meta-analysis showed that improvements in cardiovascular health can be attributed to cycling for both recreational and commuting purposes.[5] Increasing cycling may be one mechanism through which to reverse the ongoing obesity epidemic in the United States. Bassett Jr. and colleagues (2008) examined prevalence of active transportation across European and North American countries and Australia and found an inverse relationship with obesity rates.[6] Population-based surveys of workers in Sweden and Australia have shown an inverse association between walking or biking to work and overweight and obesity, although the Australian study did not observe the same association in women.[7,8] Australian men cycling to work were half as likely to be overweight and only a third as likely to be obese compared to men who drove. Smaller reductions in the likelihood of being either overweight or obese were observed in the study of workers in southern Sweden.

While cycling has known health benefits, there are risks involved as well, particularly for on-road cycling, which makes cyclists vulnerable to collisions with MVs and exposes them to vehicle exhaust. Studies have estimated that the health benefits from the physical activity cycling provides are greater than the risks from MV crashes and pollution.[9,10] Despite these findings, concerns regarding the safety of on-road cycling persist and the real risk of bicyclist-MV crashes remains a strong deterrent to cycling for many people. Various surveys have shown that perceptions of on-road cycling as unsafe persist[11,12,13,14] and safety concerns are more prevalent among women.[15,16] In order to make local community environments safer for cyclists so that the public health benefits from cycling can be seen on a broader scale, research is needed to inform planners and policy makers about the effectiveness of potential infrastructure and built-environment improvements. Findings from safety studies need to be communicated to the public, in turn, so that potential riders are aware of the safest options for cycling in their neighborhoods. A growing body of literature shows that improvements in cycling infrastructure influence ridership, cyclist behavior, and may be related to bicycle-MV crash incidence and outcomes.

Like many other American cities, the city of Chicago has made increasing cycling among residents a priority over the last two decades and has implemented on- and off-road infrastructure improvements to facilitate cycling, including installation of bike lanes and MSLs. Much of the literature on the safety of bicycle facilities comes from European studies conducted in contexts with mixtures of transport modes and infrastructure different from those found in many US cities. Adding to a growing body of literature on bicycle facilities in the United States, this study is a multiyear cross-sectional analysis of MV road collisions involving pedal-cyclists in Chicago using traffic crash report data from IDOT. The primary purpose of this study is to provide a preliminary assessment of the relationship between presence of specific on-road bicycle facilities and the occurrence of injury to cyclists in MV-bike crashes that take place on roadways within the city limits, and to determine whether these relationships vary depending on whether a crash occurs in an intersection or mid-block.

1.2 Cycling Trends and Ridership

Limited population-based survey data exist on bicycling behaviors in the United States. The US Department of Transportation's National Household Travel Survey (NHTS) collects information about trips for both recreational and commuting purposes by all ground transport modes. Findings from the most recent edition of that survey, from 2009, suggested that on average, Americans spend 20 minutes per day walking or biking, with adults reporting more daily minutes than children under age 16, particularly older adults (age 65 and above).[17] In 2009, bicycling accounted for 1% of all trips made in the United States, a 20% increase since the previous survey in 2001.[18] The recent NHTS data also show that short trips of less than 1 mile, or those that are most relevant for potential bicycling and walking uptake, account for 28% of all trips. Three-year estimates from the 2008–2010 American Community Survey (ACS) put the number of Americans traveling to work by bicycle at around 760,000.[19] Pucher et al. compiled data from the NHTS and the ACS, reporting that cycling for utilitarian purposes has been increasing and is more prevalent in urban centers (0.6% of workers compared with 0.16% in rural areas).[20] They also found that cycling continues to be a predominantly male activity, with 76% of all bike trips being taken by males, up from 67% in 2001, and they argue that the cycling increases of the last decade are primarily attributed to men between the ages of 25 and 64. Additionally, cycling among racial/ethnic minorities is up from 2001, with increases between 2% and 3% of all trips each for Blacks, Hispanics/Latinos, and Asians, though Whites account for 77% of all bike trips.[21] One analysis of 2001 NHTS data found that immigrants to the United States were more likely than native citizens to report using a bicycle even after controlling for personal and neighborhood characteristics associated with cycling.[22]

The decision to ride a bicycle at all, or as a means of transportation to work or school, may be affected by many factors including relative cost, distance, climate, and perceptions of safety. These perceptions of bicycling safety are particularly important for on-road cycling, as opposed to cycling that occurs on bike- or multiuse paths and trails, and thus also for utilitarian bicycle travel because this type of travel is more likely to take place on roadways.[23] Urbanization is a key factor related to both cycling rates and infrastructure for a number of reasons. Previous research has identified features of urban environments that are more conducive to active transportation (both walking and biking) such as increased density and connectivity.[24,25,26,27] Bicycling safety perceptions in a particular city are likely to be informed by the overall transportation picture (e.g., traffic patterns, public transit options, density, and distance) as well as the presence and type of cycling facilities such as bike lanes or paths, which vary widely across communities. Survey data suggest current and potential cyclists perceive a need for increased cycling infrastructure in the form of marked bike lanes and bike paths.[28] When researchers conducting an evaluation of bicycle lane marking treatments in Cambridge, Massachusetts asked cyclists at baseline about the best way to improve riding conditions on a common cycling thoroughfare, 60% responded to the open-ended question by stating that adding a bike lane would be best, while the next most frequent suggestion (approximately 13% of responses) was to remove street parking.[29] Cyclists have reported that either they currently do or would consider changing their trip routes to utilize available cycling facilities like bike lanes and paths. One survey of commuter cyclists in San Francisco found that among trip route characteristics, presence of a bicycle lane was the second most important feature after overall trip travel time.[30] Tilahun et al. surveyed non-faculty university employees to determine what trade-offs between cycling facilities and travel routes would be acceptable, finding that respondents were willing to incur increased travel times in order to utilize designated on-road bike lanes, and that the absence of street parking and availability of off-road bike paths were also desired.[31]

2. CRASH AND INJURY RESEARCH

2.1 Cyclist Injury and Mortality

The numbers of traffic-related injuries and fatalities to cyclists were largely steady from 2000 to 2010 according to National High Transportation Safety Administration (NHTSA) data.[32,33] Figure 1 shows the estimated injuries and fatalities to cyclists from crashes with MVs between 2000 and 2010. A spike in the number of cyclist injuries did occur in 2008, when an estimated 52,000 cyclists sustained injury, and that number remained high through 2010. Fatalities peaked in 2005 at 784 and declined in subsequent years. The share of cyclist fatalities as a percentage of overall MV crash fatalities has not varied substantially, representing about 2% of fatalities in 2010. According to Fatality Analysis Reporting System (FARS) data, more than 80% of these fatalities were men.[34]

Figure 1. Cyclists Injured or Killed in Motor Vehicle Crashes in the United States, 2000–2010.

Overall age-adjusted rates of nonfatal cyclist injury from traffic crashes in the 2000s have ranged from a low of 62.1 per 100,000 in 2002 to a high of 79.6 per 100,000 in 2004 at which point the annual rate declined through 2009 before increasing in 2010 and 2011, according to the Center for Disease Control and Prevention's Web-based Injury Statistics Query and Reporting System (WISQARS), which is based on data from the National Electronic Injury Surveillance System - All Injury Program.[35] These rate estimates are based on substantially higher injury figures than are found in transportation data, reflecting a common discrepancy between the reporting of cyclist injuries through police traffic crash reports and emergency medical service or hospitalization sources. In 2010, WISQARS recorded 213,207 nonfatal traffic-related cycling injuries compared to 52,000 reported by NHTSA, a four-fold difference. The scope of all bicycling injuries is much broader still. There were nearly 516,000 unintentional nonfatal bicyclist injuries recorded in WISQARS in 2010, including all injury severity levels and both on- and off-road incidents, such as falls. Children in particular are likely to experience bicycle injuries that do not occur on a roadway or as a result of a collision with a MV, given that they are less often riding on the roadway. Mehan and colleagues used National Electronic Injury Surveillance System data to study bicycle-related injuries sustained by youths under age 18 in the United States and found that 39.4% of the injury events that included location information occurred in the street, while 88.1% of fatalities did.[36] Additionally, children injured in the street were twice as likely to require hospitalization. They did not have specific information about which cases resulted from collisions with MVs, however. Similarly, a three-state study of emergency department data on pedestrian and cyclist injury found that 70% of the bicycle injury events did not involve a crash with a MV.[37] However, the injuries sustained by those cyclists involved in MV crashes were greater, with the cyclists more likely to be hospitalized, especially if the crash occurred while the bicyclist was traveling on the roadway compared to an off-road location. The WISQARS data show that approximately 70% of hospitalized bicyclists were involved in MV crashes that occurred on a roadway in 2010. Thus, while bicycle-MV crashes may represent only a minority of all bicyclist injury events, they are the most serious and costly.

Rates of nonfatal traffic-related bicycling injury vary by gender and age. Age-adjusted incidence for males was 107.5 per 100,000 in 2010, compared with 34.3 per 100,000 for females among all ages. Incidence for males has been approximately three times the rate for females every year going back to 2001. This disparity largely reflects gender differences in cycling rates and behavior. With respect to age, crude injury rates were highest among 10–14 year olds, (164.2 per 100,000) and 15–19 year olds (128.9) in 2010, compared to persons age 20–24 (96.6) and 25–29 (80.1). Rates were between 60 and 72 per 100,000 for 30–54 year olds and declined for older adults and seniors. While injury rates may be highest for older children and adolescents, actual injury severity and mortality risk may follow a different pattern. A study based on the National Trauma Databank found that cyclists 65 years of age and older were at greater risk for upper extremity, pelvic, or spinal fractures; head injuries; and death from crashes with automobiles compared to the youngest age group of children 14 and under.[38]

2.2 **Crash Factors**

A multitude of factors lead to cyclist crashes. According to FARS data, the majority of fatal crashes occur in clear weather, during the spring and summer months, on the roadway in the automobile travel lane, when the cyclist is male and not wearing a helmet, when the cyclist is traveling with traffic as opposed to against it, and outside of an intersection.[39] More than half of the 625 fatal cyclist crashes recorded by FARS in 2010 occurred during daylight hours, and those crashes that took place after dark occurred with equal frequency under lit or unlit road conditions, representing 20% of crashes each. Forty percent of crashes happened on minor and principal urban arterial roads, while an additional 20% were on local urban streets. Speeding was not a factor in the majority of crashes that resulted in a cyclist death. Minor children were less likely to be involved in a fatal cycling accident than were adults. The bicyclist was determined to have a blood alcohol content above the legal limit of 0.08% in only 12.7% of fatal crashes. In comparison, 44% of crashes did not involve alcohol and 2.7% involved a cyclist who had a blood alcohol content within the legal range. With respect to location, the majority of fatalities (69%) occurred in the travel lane compared to 12% in the bicycle lane or paved shoulder and 11% in a sidewalk or crosswalk. About 40% of the fatal crashes happened in an intersection or were intersection-related, while 58% were on the non-intersection roadway and less than 1% were off-road. Only 16% of the cyclists involved in fatal crashes were wearing a helmet at the time.

Beyond crash surveillance, researchers have extensively examined the factors related to bicycle-MV crashes, from individual cyclist characteristics and behavior to environmental conditions and infrastructure. Historically, cyclist injury research and prevention efforts have focused largely on helmet use, and a thorough body of literature has shown that wearing a helmet protects against head and brain injury in cyclist-MV crashes.[40,41,42] One study also found that cyclists wearing helmets were more likely to practice other safe behaviors such as making legal stops at intersections and using hand signals in advance of turning compared to non-helmeted cyclists.[43] Despite the protective effect of helmet use for certain head injuries, in reality cyclists involved in crashes sustain many other injuries for which a helmet provides no protection. Research on cycling safety has shifted since the 1990s away from a focus on individual behaviors and characteristics towards identifying infrastructural factors associated with crashes and injuries, including various bicycle facilities. Specifically, studies have tried to determine if bicycle infrastructure, such as designated on-road bicycle lanes or physically separated cycle tracks, actually makes cycling safer. If facilities such as bike lanes and off-road paths are shown to reduce risk of crashes or the resultant health and cost consequences, installing them in more communities may be an important tool of primary injury prevention.

2.3 **Bicycle Infrastructure**

Much of the literature suggests that bicycle facilities may reduce the risk of both crashes and injury, but contradictory results have also been found and there may be differences by type of facility. In a 2009 literature review, Reynolds et al. found that among studies focused on road and lane conditions, findings were generally consistent that demarcated bike lanes, bike routes, and bike paths were safer for cyclists compared to "unmodified" roadways, sidewalks, and off-road multiuse paths that are shared with joggers and skaters.[44] They also identified a second set of mostly European studies that focused on intersection features (roundabouts or bike crossings), rather than road and lane characteristics, and this research suggests that installation of roundabouts led to increased crash risk for cyclists if there was not a cycle track (i.e., a physically separated, protective bike lane), while findings from the bike crossing studies were mixed. In contrast to the findings from other studies of bike lanes, survey data on cyclists in Portland, Oregon showed events that resulted in injury or required medical attention occurred primarily while the cyclist was riding in a bike lane or wide shoulder, or on a residential street. However, the analyses did not control for important factors such as cyclist gender, age, estimated miles commuted annually, or environmental factors.[45] Furthermore, most cyclists reported riding on such facilities, which are more common in Portland than in other American cities, as it is known for its bike-friendly culture and progressive transportation infrastructure; therefore increased exposure to bike lanes and wide shoulders likely confounded the observed association.

Studies in large cities that have extensive systems of bike infrastructure but where such infrastructure still constitutes a small fraction of the street network are well situated to assess the relationship between cycling facilities and crashes. Like many cities around the United States, New York has been increasing the extent of its bike lanes since the 1990s. Chen and colleagues conducted a quasi-experimental study with matching at the street segment and intersection level, comparing crash incidence by the presence of a bike lane before and after the lanes were installed.[46] They found that installation of the lanes led only to a slight but not statistically significant increase in bicyclist crashes in segments compared to the locations without bike lanes, but total crashes, multiple-vehicle crashes, pedestrian crashes, and injurious crashes decreased more in the segments where bike lanes were installed. All crash categories increased at intersections near where bike lanes were present, but those differences were not statistically significant. The authors attributed the higher number of crashes to substantially increased bicycle ridership in New York during the study period, although clear data on that phenomenon were not available, a problem common to most studies in this literature. In Toronto, Teschke et al. conducted a case-crossover study of injurious crashes across 14 types of cycling facilities, comparing the infrastructure present at the crash location with a randomly selected control area on the same trip route.[47] Results showed that cycle tracks were the safest facility compared to the reference type, which was a major street with on-street parking and no bicycle facility. Streets with demarcated but not separated bike lanes had reduced risk of injury, but the difference was only marginally statistically significant. In addition to the novel design, a strength of the study was that on-site environmental audits were conducted along with traffic counts at all locations involved in the analysis, allowing the researchers to control for varying cycling levels across different facility types. Taken together, this literature suggests a protective effect against crashes and resulting injuries for certain types of bicycle facilities compared to untreated roads.

In addition to the potential safety effect of bicycling facilities, crash outcomes may also vary by crash location relative to an intersection. Intersection and mid-block settings involve different actions and maneuvers by drivers and cyclists, and one way to examine the effect of location is to compare crashes that occur in or near intersections with those that occur elsewhere on the roadway. Moore et al. did this using data on bicycle crashes in Ohio between 2002 and 2008, finding that several risk factors differed by crash location.[48] Overall, 59% of the 10,029 bicycle-MV crashes occurred in an intersection and 41% were non-intersection-related. They observed that several factors (e.g., dry pavement, automobile drivers under the influence of alcohol, heavy-duty trucks, front of MV impacting the side of a bicycle) were associated with greater injury severity among all crashes, but there were numerous differences in the injury outcome based on whether the crash was intersection-related or not. For example, a non-helmeted cyclist, uninsured driver, involvement of a pickup truck or van, and a crash on a horizontal curve or with grade were associated with more severe injuries in intersection crashes. At non-intersection points, summer months, a bicyclist under the influence of drugs, increasing cyclist age, and a driveway-related crash, were all associated with increased injury severity. Using data on crashes involving motor vehicles and both cyclists and pedestrians in Montreal, Zahabi et al. found that only bicycle-MV collisions occurring at signalized intersections and involving straight movement of the vehicle were associated with cyclist injury severity.[49] Speed limit, occurrence on a major road, and involvement of a van, truck, or bus were not found to be related. In addition to potentially different risk factors by crash location, the safety effect of bike facilities may vary based on whether a crash happens mid-block or in the middle of an intersection, given that bike lane and MSL markings typically do not extend past the crosswalk into an intersection.

2.4 **Study Context**

The city of Chicago has been promoting cycling for more than 20 years, publishing periodic plans on the cycling network, bike facilities, and education efforts. The original 1992 version of the Bike 2000 Plan called for establishing 100 miles of on-street bike lanes and 50 miles of off-street trail network, as well as 10,000 bike racks and expanded public transit options for cyclists, among other initiatives.[50] The newest edition, the Bike 2015 Plan, highlights how far the city has come in its transformation into a cycling-friendly destination. The city had met its goal for designated bike lanes by 2005, and by 2010 it had doubled its network compared to 2000.[51] The new plan calls for 150 miles of bike lanes by 2015, along with increases in all other infrastructure configurations, including bike routes, MSLs, off-road trails, and 10 miles of bike boulevards for a total of 500 miles of cycling facilities over the street network.

As of 2010, Chicago was still lagging behind other cycling-friendly cities like Portland, Minneapolis, Washington DC, and San Francisco in the miles of bike lanes per capita.[52] However, the effects of the recent recession and widespread cuts in government spending have led some to question the importance of new cycling facilities relative to other public safety improvements. While researchers, planners, bicycling organizations, and students have assessed the spatial distribution of bicycle-MV crashes in Chicago, and more recently, efforts have been made to count cyclists at designated intersections across the city, there appears to be no published statistical analysis of the effect of bike lanes on bicycle-MV crashes and injury severity.

The purpose of the present study is to examine the relationships between location and roadway characteristics of these crash incidents and determine whether bike lanes and other types of facilities confer a protective effect with respect to cyclist injury. For example, recommended bike routes, which contain roadside signs bearing an image of a bike but no on-road markings or designated space for cyclists, may not actually function differently than regular untreated roads. Additionally, an exploratory analysis of bus stops is included to identify whether bus stop location (as a proxy for presence of a public transit bus) may be associated with crash occurrence or injury. In particular, this study has three objectives:

1. To assess the effect of cycling facilities, specifically designated on-road bike lanes, MSLs, and recommended bike routes, on crash prevalence and injury;
2. To determine whether bus stop location is related to cyclist injury; and
3. To identify how the relationships between environmental, personal, and infrastructure factors and cyclist injury differ based on crash location (at an intersection or mid-block).

This cross-sectional analysis utilizes official traffic crash records from IDOT over a three-year period along with GIS data on the location of bicycling facilities and bus stops throughout the city of Chicago.

3. METHODS

3.1 Data and Measures

Data on police-reported MV crashes in the state of Illinois were obtained for the years 2008, 2009, and 2010 from IDOT, which maintains databases on these road crashes at the crash, person, and MV levels. Reportable crashes for the IDOT Crash Information System are those that result in an injury or fatality or involve property damage equal to or greater than $500, and occur on a roadway (including alleys and driveways). The present study included only crashes that occurred within the city of Chicago and involved a pedal-cyclist. The case number of each eligible crash incident was used to link data from the main crash file to the person and vehicle files. Figure 2 depicts the IDOT file structures. Because the focus of the study is on-road cycling facilities such as bike lanes, crashes that did not occur on a roadway (n=429) or that were missing this designation (n=341) were excluded from all analyses. Cases without valid geographic coordinates (n=63) were excluded because they could not be linked to the main infrastructure measures. Variables in the crash file include reporting, location, environmental, and roadway characteristics as well as crash cause and whether or not the collision was intersection-related. Person-level data collected by IDOT includes age and sex of those involved, count of injuries sustained, safety equipment (e.g., helmet, airbag), driver and cyclist action (e.g., riding with or against traffic, crossing, improper passing, following too closely), driver condition (e.g., normal, impaired, asleep/fainted), and other items such as cyclist visibility (was the cyclist wearing contrasting clothing, reflective material, or a light source). Injury severity was coded on a five point scale (0=no indication of injury, 1=possible injury, 2=non-incapacitating injury, 3=incapacitating injury, and 4=fatality). Incapacitating injuries were nonfatal and included severe lacerations, broken limbs, and skull, chest, or abdominal injuries. Non-incapacitating injuries included only those apparent at the time of the crash.

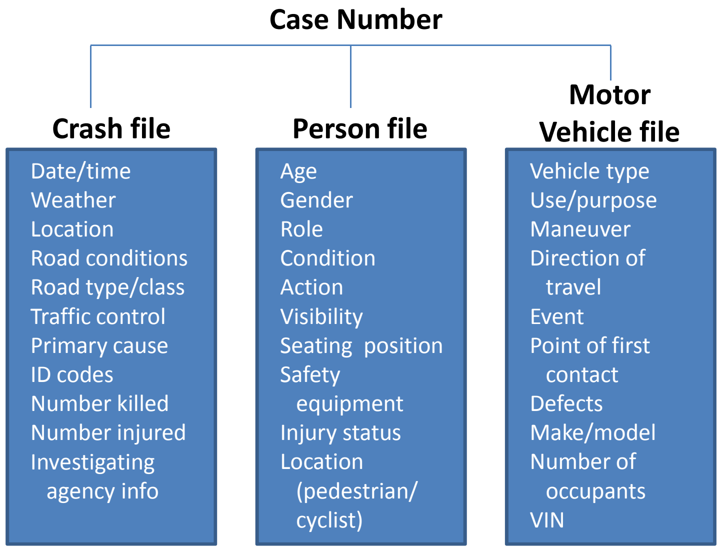

Figure 2. Illinois Department of Transportation Statewide Motor Vehicle Crash Data Schematic.

scene, such as abrasions, bruises, bumps or swollen areas, or minor lacerations. Possible injuries were those not included in the other categories, such as claims of pain or injuries not evident, limping, nausea, and momentary unconsciousness. Finally, the IDOT vehicle file contains data on the MV type and purpose (personal, commercial, public transit, emergency services), defects, and the maneuver executed prior to the crash, among other variables.

Relevant categorical variables were recoded to dichotomous indicators, including roadway characteristics and infrastructure factors such as road type (arterial, collector [i.e., streets with low-to medium-capacity traffic intended to connect local streets to principal arterial roads], and local streets), two-way road, presence of any road defect (e.g., construction zone, ruts or holes, debris), any traffic control device and more specifically whether a traffic signal/flasher or stop sign was present, and straight and level alignment. Environmental variables were daylight at the time of the crash, clear weather condition, precipitation, and dry road surface. Dichotomous person variables included categorical age and both driver and cyclist actions prior to the crash (e.g., no action, riding with traffic, riding against traffic, failure to yield, turning). It should be noted that the categories for driver action were not the same as for cyclist action. For the outcome measure, a dichotomous variable for any incapacitating or fatal injury was coded when preliminary analyses showed that the injury measure could not be appropriately modeled on an ordinal scale. Finally, dichotomous variables for type of MV (passenger car; sport utility vehicle, pick-up truck, or van/mini-van; bus; and truck), point of impact, and MV maneuver before the crash were also coded.

Using ArcMap 10[53], the crash latitude and longitude were plotted and joined to GIS layers obtained from the City of Chicago[54], including designated Chicago Transit Authority (CTA) bus stop points and bike lanes and recommended bike routes throughout city streets. The bike lane data included the specific type of cycling facility present, such as an existing designated bike lane, a MSL for use by both bicycles and MVs, a recommended bike route with signage without a lane, an access path, or an off-road trail. Some records contained the year of installation of the bike route or facility, but the majority of records were missing this information. In order to link the crash points to routes or facilities that were present at the time of the crash, an installation date was coded as the midpoint of the year (July 1) for facilities installed in 2008, 2009, or 2010. Therefore, roughly half of the crashes in each of the three years would fall on either side of this date. Records missing the installation year were assigned the date of December 31, 2007, making them present as of the start of the study period because older routes and facilities were less likely to have installation year included on the file (email communication with City of Chicago employee, 2012). Each crash point was linked to a bike facility via a spatial join if a facility was present within three distance cut points: 20, 30, and 40 feet. This was done because the bike facility file represents street centerlines and the crash points typically fell off those lines. Cases with discrepant bike facility matching by distance cut point were reviewed and the 40-foot distance was used for the final analysis as it was more inclusive for crashes on wider roads with a bike route or facility. Dichotomous indicator variables were coded for presence of an existing designated bicycle lane, a MSL, or a recommended bike route to be used as the primary independent variables.

The near analysis function in ArcGIS was used to identify the closest CTA bus stop point to the crash points, if one was located within 250 feet. Using the calculated distance, indicator variables were coded for presence of a bus stop within 100 and 50 feet of the crash location. A small number of flag stops, or those that are not permanently designated but where an individual can flag down a passing bus in order to board were excluded. The bus stop file was dated September 2007 and included any stops that were being planned at the time and scheduled for installation in winter 2008 in order to best reflect bus stop locations at the start of the study period.

3.2 **Statistical Analysis**

Descriptive statistics were calculated for crash characteristics as well as cyclist, driver, and vehicle attributes, and the presence of a bicycle facility or bus stop near the crash by injury status, stratified by crash location (intersection or non-intersection). Chi-square tests and Fisher Exact tests were used to assess the difference between these factors and injury status for dichotomous and categorical variables while independent sample t-tests were used for continuous variables. Among all cases, differences in the event characteristics and person/vehicle attributes by study year were examined using the same procedures along with a non-parametric test for trend where incidence increased or decreased by year. Driver and MV data were aggregated to the crash level and then merged to the cyclist data so that the unit of analysis was cyclists. For example, if a single cyclist was involved in a crash with two MVs, a passenger car and a van, the final cyclist-level file would have dummy variables for both of these vehicle types coded as 1 for that cyclist.

Logistic regression was used to model incapacitating or fatal injury occurrence to determine whether or not the presence of specific bicycle facilities was associated with incapacitating or fatal injury risk while controlling for important covariates, separately for intersection-related and non-intersection crashes. In addition to the dummy variables for a bike lane, MSL, and bike route, cyclist and driver ages, dummy variables for study years 2009 and 2010 (with 2008 as the reference), seasons (spring, summer, and fall), and road type (arterial, collector, local street—both arterial and local streets used as reference in different models) were tested in the multivariable models because they may be important factors that could explain time trends or be related to the injury outcome, but these variables were dropped from the final models if not at least marginally statistically significant. Inclusion of other variables was based on the results of the bivariate associations with incapacitating or fatal injury and results from manual backward and stepwise selection procedures. Once a suitable combination of covariates was identified separately for intersection and non-intersection crashes, interactions were tested for covariates that were conceptually related. For example, a product term for roadway characteristics included a one-way street and a bike lane. None of the interactions tested were statistically significant for either intersection or non-intersection crashes. Stata version 11 was used to run all final analyses.[55]

4. RESULTS

4.1 <u>Descriptive Results</u>

There were 4,825 bicycle-MV crashes in Chicago recorded by IDOT between 2008 and 2010. Of these, 4,031 were eligible for the analysis based on having occurred on a roadway and containing geo-location information in the dataset. These eligible crashes involved 4,059 cyclists. The highest number of crashes—1,420—occurred in 2010; 2009 had the lowest, with 1,250. Figure 3 displays the temporal patterns by month, which were similar across the three years with large increases in the summer months. A peak of 253 crashes occurred in July 2008, the highest number for a single month over the three-year period. July was also the peak month in 2009 at 205 crashes, while August was the peak month in 2010 with 231. December and January were the months with the lowest number of incidents.

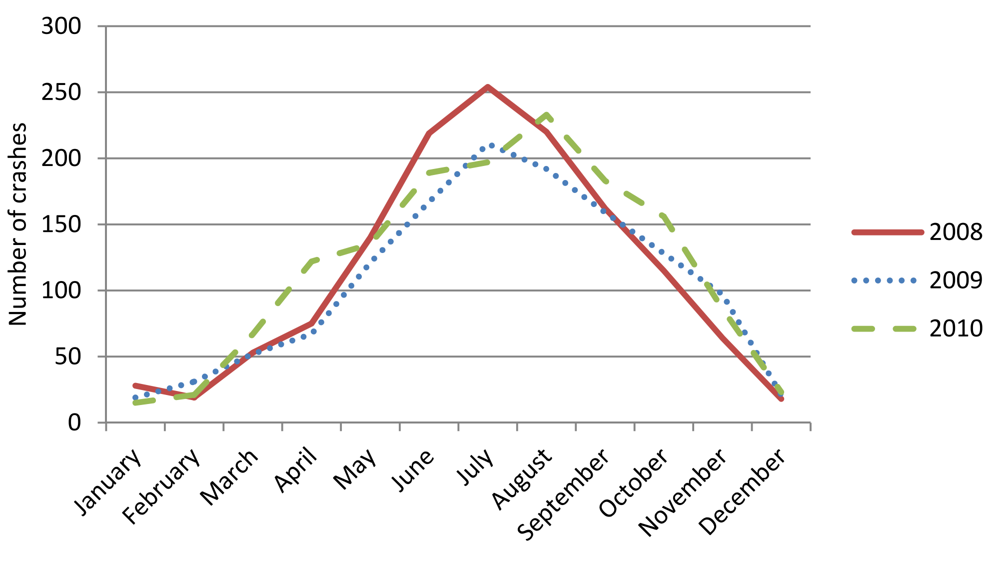

Figure 3. Police-Reported Motor Vehicle-Bicycle Crashes in Chicago by Month, 2008–2010, Illinois Department of Transportation Data.

Fifteen cyclist fatalities were documented in the original crash dataset over the 3-year period, but one occurred in an alley or driveway and the other was missing coordinates and thus these cases were excluded from the final analyses. The overall case-fatality rate among on-road crashes reported to police was 0.32%. Injuries were common among the police-reported MV-bike crashes. Incapacitating injuries such as abrasions and bruises represented the largest share of cases at 47%, followed by possible injuries at 37%. Nine percent to 10% of the cyclists involved in a reported crash experienced an incapacitating injury that would have likely resulted in hospitalization. A very small proportion of cyclists (10% in 2008 and less than 5% in both 2009 and 2010) were coded as having no injury after the crash. Figure 4 shows the distribution of injury severity by study year, which varied overall ($\chi^2 = 77.33$, $p<.0001$). The proportion of non-incapacitating injuries increased 8% in 2010 while cases with no injury decreased each year ($z=-7.87$ for trend, $p<.0001$). More possible injuries were reported in 2009. The proportion of fatalities and incapacitating injuries did not vary.

Slightly more than half of all police-reported crashes occurred on or near a bicycle facility (data not shown). Of these, 17.5% were on a street with a designated bike lane, 7.8% on a street with a shared lane, and 28.6% near a recommended bike route. A slightly greater percentage of non-intersection crashes occurred near a designated bike lane compared to intersection-related crashes (19.6% versus 16.0%, $p<.0001$). A smaller difference was observed for crashes on marked shared-lane roads (8.8% of non-intersection crashes versus 7.1% of intersection-related crashes, $p=.0412$). Intersection-related crashes were substantially more likely to occur on or near a recommended bike route (34.1% versus 20.9%, $p<.0001$). With respect to cyclist injury status, there were no significant differences in the proportion of crashes occurring on each type of bike facility for intersection crashes or non-intersection crashes at the 5% level. However, there was a marginally significant association between a

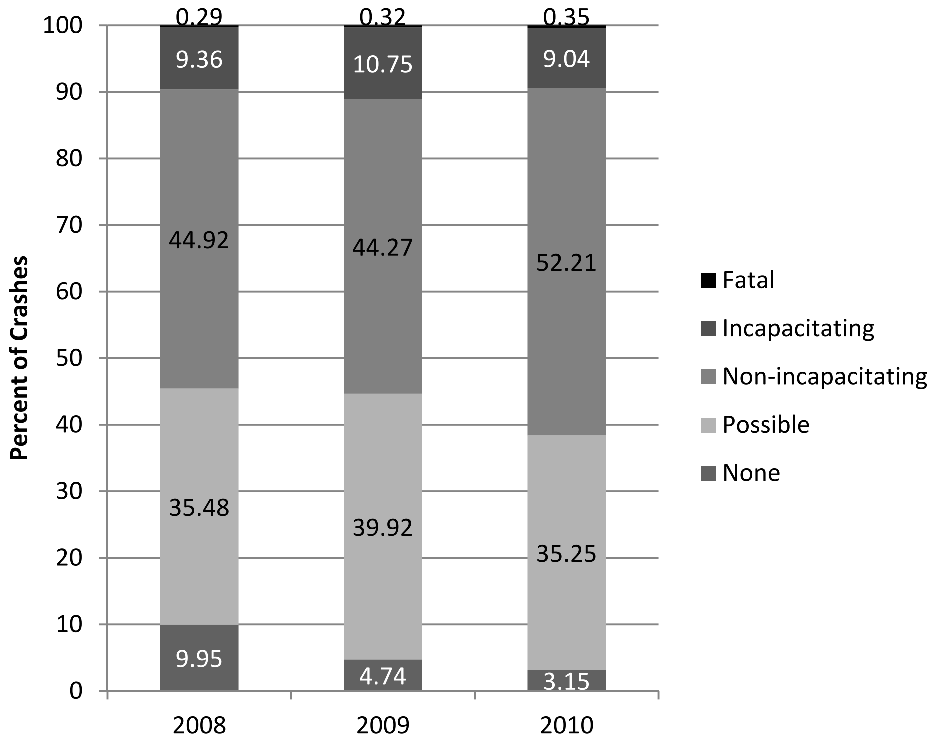

Figure 4. Distribution of Cyclist Injury Severity in Motor Vehicle-Bicycle Crashes in Illinois by Year, 2008–2010, Illinois Department of Transportation Data.

recommended bike route and injury, with a higher percentage of non-injury or minor injury crashes injury crashes occurring on a bike route (34.7% versus 29.0% of severe injury crashes, p=.0783).

Approximately 50% of all crashes occurred within 100 feet of a bus stop and just under one-third were within 50 feet. Given that CTA bus stops are typically placed at intersections, the non-intersection crashes were less likely to have a bus stop nearby. Nearly 90% of all eligible crashes occurred during clear weather with dry road conditions, and 72.2% were during daylight hours. Most crashes were on two-way roads with a mean lane count of 2.5. Major or minor arterial roads and collector streets accounted for the largest shares of crashes (42.5% and 37.2%, respectively) with the remaining 20%

taking place on local streets. Intersection crashes were significantly more likely to occur on arterial roads (49.2% versus 32.8%, p<.0001), whereas a larger proportion of non-intersection crashes were on collectors (41.2% versus 34.4%, p<.0001) and local streets (25.7% versus 15.1%, p<.0001) compared with intersection crashes (not shown).

Tables I–III contain descriptive statistics for crash conditions, person characteristics, and MV characteristics, respectively, for the intersection-related crashes by injury status. Few crash conditions varied significantly by injury (Table I). A cyclist riding against traffic or crossing against a signal was positively associated with serious or fatal injury; a cyclist crossing with a signal was negatively associated with these outcomes (Table II). Other cyclist actions were unrelated to injury status.

TABLE I

INTERSECTION CRASH CONDITIONS BY CYCLIST INJURY STATUS

Variable	Total N=2384	No/Minor Injury N=2143 (89.9%)	Incapacitating or Fatal Injury N=241 (10.1%)	p-value
Temporal and Environmental Factors				
Year				
2008	808 (33.9)	734 (34.3)	74 (30.7)	.2702
2009	747 (31.3)	654 (30.5)	93 (38.6)	.0104
2010	829 (34.8)	755 (35.2)	74 (30.7)	.1619
Season				
Winter	158 (6.6)	140 (6.5)	18 (7.5)	.5797
Spring	629 (26.4)	559 (26.1)	70 (29.1)	.3228
Summer	1086 (45.6)	982 (45.8)	104 (43.2)	.4300
Fall	511 (21.4)	462 (21.6)	49 (20.3)	.6600
Clear weather	2048 (85.9)	1845 (86.1)	203 (84.2)	.2020
Precipitation	223 (9.4)	195 (9.1)	28 (11.6)	.2245
Dry road surface	2038 (85.5)	1833 (85.5)	205 (85.1)	.5456
Daylight at time of crash	1667 (69.9)	1506 (70.3)	161 (66.8)	.1984
Roadway Attributes				
Two-way road	2139 (89.7)	1922 (89.7)	217 (90.0)	.8637
One-way road	245 (10.3)	221 (10.3)	24 (10.0)	.8637
Number of traffic lanes — mean (SD)	2.7 (1.4)	2.7 (1.4)	2.8 (1.2)	.2703
Type of Street				
Major or minor arterial street	1169 (49.0)	1051 (49.0)	118 (49.0)	.9810
Collector street	819 (34.4)	735 (34.3)	84 (34.9)	.8629
Local street	365 (15.3)	329 (15.4)	36 (14.9)	.8654
Straight and level alignment	2299 (96.4)	2067 (96.5)	232 (96.3)	.3309
Any road defect present	50 (2.1)	43 (2.0)	7 (2.9)	.4255
Any traffic control device	1861 (78.1)	1680 (78.4)	181 (75.1)	.2205
Traffic signal, stop sign, or flasher	1827 (76.6)	1649 (76.9)	178 (73.9)	.2621
Bicycle Facility				
Designated bike lane	381 (16.0)	336 (15.7)	45 (18.7)	.2292
Designated shared lane	169 (7.1)	151 (7.1)	18 (7.5)	.8085
Recommended bike route	814 (34.1)	744 (34.7)	70 (29.0)	.0783
No bicycle facility	1020 (42.8)	912 (42.6)	108 (44.8)	.5021
CTA bus stop within 100 feet	1455 (61.0)	1306 (60.9)	149 (61.8)	.7898
CTA bus stop within 50 feet	914 (38.3)	816 (38.1)	98 (40.7)	.4336

Notes: Percent values shown include missing cases in the denominator. P-value for chi-square test including valid responses only.

Table II

CYCLIST AND DRIVER CHARACTERISTICS BY CYCLIST INJURY STATUS, INTERSECTION CRASHES

Variable	Total N=2384	No/Minor Injury N=2143 (89.9%)	Incapacitating or Fatal Injury N=241 (10.1%)	p-value
Cyclist Characteristics				
Male	1761 (74.9)	1581 (75.0)	180 (74.7)	.9255
Age—mean(SD)	34.7 (21.9)	34.8 (22.2)	33.2 (18.8)	.2569
Under 18	398 (16.7)	366 (17.1)	32 (13.3)	.1336
18–29	930 (39.0)	825 (38.5)	105 (43.6)	.1260
30–49	615 (25.8)	553 (25.8)	62 (25.7)	.9788
50–69	259 (10.9)	230 (10.7)	29 (12.0)	.5385
70 or older	32 (1.3)	26 (1.2)	6 (2.5)	.1236
Unspecified age	150 (6.3)	143 (6.7)	7 (2.9)	.0224
Wearing reflective clothing/light source	719 (30.2)	642 (30.0)	77 (32.0)	.6469
Cyclist Action				
Riding with traffic	661 (27.7)	594 (27.7)	67 (27.8)	.6890
Riding against traffic	213 (8.9)	185 (8.6)	28 (11.6)	.0781
Crossing with signal	445 (18.7)	413 (19.3)	32 (13.3)	.0388
Crossing against signal	238 (10.0)	205 (9.6)	33 (13.7)	.0230
No action	63 (2.6)	58 (2.7)	5 (2.1)	.6207
Enter from driveway	11 (0.5)	11 (0.5)	0 (0)	.2741
Turning left	77 (3.2)	67 (3.1)	10 (4.2)	.3301
Turning right	44 (1.9)	42 (2.0)	2 (0.8)	.2385
Intoxicated/Impaired	11 (0.5)	10 (0.5)	1 (0.4)	.9405
Other action	256 (10.7)	237 (11.1)	19 (7.9)	.1778
Unspecified cyclist action	365 (15.3)	321 (15.0)	44 (18.3)	.1802
Driver Characteristics*				
Male	1177 (49.4)	1040 (48.5)	137 (56.9)	.0449
Age – mean(SD)	42.0 (15.6)	42.0 (15.6)	41.8 (15.4)	.8120
Driver Condition				
Normal	1716 (72.0)	1529 (71.4)	187 (77.6)	.0007
Intoxicated, impaired, or fatigued	13 (0.6)	8 (0.4)	5 (2.1)	.0016
Unspecified driver condition	658 (27.6)	607 (28.3)	49 (20.3)	.0084
Driver Visibility				
Clear visibility	1284 (53.9)	1155 (53.9)	129 (53.5)	.1301
Visibility obscured by parked vehicle	19 (0.8)	16 (0.8)	3 (1.2)	.4522
Visibility obscured by moving vehicle	60 (2.5)	49 (2.3)	11 (4.6)	.0441
Visibility obscured by other object	130 (5.5)	115 (5.4)	15 (6.2)	.6949
Unspecified driver visibility	893 (37.5)	809 (37.8)	84 (34.9)	.3785
Driver Action				
Failure to yield	847 (35.5)	753 (35.1)	94 (39.0)	.4665
No action	688 (28.9)	622 (29.0)	66 (27.4)	.3179
Disregard traffic control device	59 (2.5)	52 (2.4)	7 (2.9)	.7337
Driving too fast	20 (0.8)	15 (0.7)	5 (2.1)	.0340
Improper turn	49 (2.1)	43 (2.0)	6 (2.5)	.6913
Following too closely	16 (0.7)	15 (0.7)	1 (0.4)	.5757
Improper lane usage	16 (0.7)	16 (0.8)	0 (0)	.1683
Other driver action	207 (8.7)	186 (8.7)	21 (8.7)	.8498
Unspecified driver action	486 (20.4)	444 (20.7)	42 (17.4)	.2292

Notes: Percent values shown include missing cases in the denominator. P-value for chi-square test including valid responses only.
*Driver variables may sum to more than 100% because multiple drivers were involved in some crashes.

Table III
MOTOR VEHICLE CHARACTERISTICS BY CYCLIST INJURY STATUS, INTERSECTION CRASHES

Variable	**Total** N=2384	**No/Minor Injury** N=2143 (89.9%)	**Incapacitating or Fatal Injury** N=241 (10.1%)	**p-value**
Type of Motor Vehicle				
Passenger car	1722 (72.2)	1557 (72.7)	165 (68.5)	.0661
Van, sport utility vehicle, or pick-up truck	455 (19.1)	404 (18.9)	51 (21.2)	.4566
Bus	30 (1.3)	28 (1.3)	2 (0.8)	.5139
Truck (single unit or with semi trailer)	35 (1.5)	25 (1.2)	10 (4.2)	.0003
Other type	71 (3.0)	61 (2.9)	10 (4.2)	.2807
Unspecified vehicle type	75 (3.2)	71 (3.3)	4 (1.7)	.1633
Point of First Contact				
Front	891 (37.4)	788 (36.8)	103 (42.7)	.0694
Right or left side, center	269 (11.3)	245 (11.4)	24 (10.0)	.4929
Front quarter panel (either side)	629 (26.4)	573 (26.7)	56 (23.2)	.2422
Rear quarter panel (either side)	104 (4.4)	99 (4.6)	5 (2.1)	.0667
Other point of contact	47 (2.0)	40 (1.9)	7 (2.9)	.2728
No contact	51 (2.1)	43 (2.0)	8 (3.3)	.1824
Unspecified point of contact	400 (16.8)	360 (16.8)	40 (16.6)	.9368
Motor Vehicle Maneuver				
Straight ahead	1042 (45.2)	920 (44.4)	122 (52.1)	.0234
Left turn	448 (19.4)	393 (19.0)	55 (23.5)	.0949
Right turn	404 (17.5)	375 (18.1)	29 (13.4)	.0300
Slow/stop in traffic (incl. slow turn or loading)	236 (10.2)	225 (10.9)	11 (4.7)	.0033
Enter from driveway or alley	1 (0.0)	1 (0.1)	0 (0)	.7369
Passing/overtaking	26 (1.1)	25 (1.2)	1 (0.4)	.2851
Other maneuver	157 (6.8)	140 (6.8)	17 (7.3)	.7669
Unspecified maneuver	76 (3.2)	69 (3.2)	7 (2.9)	.1824

Note: Percent values shown include missing cases in the denominator. P-value for chi-square test including valid responses only. Motor vehicle variables may sum to more than 100% because multiple vehicles were involved in some crashes.

Several driver characteristics were also important in bivariate analyses. Crashes that resulted in a severe or fatal cyclist injury were more likely to involve a male MV driver (56.9% versus 48.5% for no/minor injury crashes) and an impaired or intoxicated driver (2.1% versus 0.4%), though driver condition was missing for more than a quarter of cases and the cell counts for impaired or intoxicated drivers were low. Severe cyclist injury in an intersection crash was also related to the driver's vision being obscured by another moving motor vehicle and the driver going too fast.

With respect to MV characteristics, a lower percent of severe injury crashes involved passenger cars than non-injury or minor injury crashes (marginal significance), whereas trucks were significantly positively associated with the severe injury crashes at intersections (Table III). A front impact to the MV was associated with serious or fatal cyclist injury, as was the MV traveling straight ahead. A greater percentage of non-injury or minor injury crashes involved the MV turning right or slowing/stopping in traffic. The two impact location differences were only marginally significant in the bivariate analyses for intersection crashes.

Roadway conditions were more important for non-intersection crashes in the bivariate analyses. Daylight and dry road surface were more prevalent among the non-injury or minor injury crashes than the severe injury crashes, whereas a greater proportion of severe injury crashes occurred on two-way and arterial roads. As with intersection crashes, an intoxicated driver and a driver going too fast were associated with severe injury crashes but there were only 11 and 16 non-intersection crashes with an impaired or speeding driver, respectively, and four of each resulted in an incapacitating or fatal injury to the cyclist. Only two MV characteristics were significantly related to injury; the MV being a passenger car and the MV making a right turn prior to the crash were both associated with more non-injury or minor injury crashes.

Cyclist intoxication or impairment did not appear to be an important factor in the collisions; overall, 0.6% of cyclists were coded as being intoxicated and there were no differences in the injury outcome. However, no BAC measure was available. Data on BAC were available for only 22 drivers (not shown); others had refused the test (n=9), were not offered the test (n=2385), were tested but with unrecorded results (n=27), or had an unknown test status (n=1127).

Table IV

NON-INTERSECTION CRASH CONDITIONS BY CYCLIST INJURY STATUS

Variable	Total N=1675	No/Minor Injury N=1510 (90.1%)	Incapacitating or Fatal Injury N=165 (9.9%)	p-value
Temporal and Environmental Factors				
Year				
2008	559 (33.4)	501 (33.2)	58 (35.2)	.6099
2009	518 (30.9)	471 (31.2)	47 (28.5)	.4750
2010	598 (35.7)	538 (35.63)	60 (36.4)	.8517
Season				
Winter	105 (6.3)	96 (6.4)	9 (5.5)	.6496
Spring	445 (26.7)	401 (26.6)	44 (26.7)	.9757
Summer	779 (46.5)	708 (46.9)	71 (43.0)	.3456
Fall	346 (20.7)	305 (20.2)	41 (24.9)	.1613
Clear weather	1484 (88.6)	1341 (88.8)	143 (86.7)	.2851
Precipitation	142 (8.5)	123 (8.2)	19 (11.5)	.1459
Dry road surface	1455 (86.9)	1318 (87.3)	137 (83.0)	.0512
Daylight at time of crash	1239 (74.0)	1134 (75.1)	105 (63.6)	.0012
Roadway Attributes				
Two-way road	1440 (86.0)	1291 (85.5)	149 (90.3)	.0914
One-way road	235 (14.0)	219 (14.5)	16 (9.7)	.0914
Number of traffic lanes — mean (SD)	2.4 (1.1)	2.4 (1.1)	2.5 (1.2)	.1428
Type of Street				
Major or minor arterial street	548 (32.7)	481 (31.9)	67 (40.6)	.0229
Collector street	688 (41.1)	627 (41.5)	61 (37.0)	.2590
Local street	435 (26.0)	399 (26.4)	36 (21.8)	.2002
Straight and level alignment	1608 (96.0)	1447 (95.8)	161 (97.6)	.2506
Any road defect present	41 (2.5)	34 (2.3)	7 (4.2)	.1026
Any traffic control device	283 (16.9)	257 (17.0)	26 (15.8)	.6687
Traffic signal, stop sign, or flasher	221 (13.2)	200 (13.3)	21 (12.7)	.8407
Bicycle Facility				
Designated bike lane	329 (19.6)	304 (20.1)	25 (15.2)	.1262
Designated shared lane	148 (8.8)	137 (9.1)	11 (6.7)	.3011
Recommended bike route	348 (20.8)	310 (20.5)	38 (23.0)	.4522
No facility	850 (50.8)	759 (50.3)	91 (55.2)	.2332
CTA bus stop within 100 feet	613 (36.6)	547 (36.2)	66 (40.0)	.3392
CTA bus stop within 50 feet	309 (18.5)	272 (18.0)	37 (22.4)	.1654

Notes: Percent values shown include missing cases in the denominator. P-value for chi-square test including valid responses only.

Table V
CYCLIST AND DRIVER CHARACTERISTICS BY CYCLIST INJURY STATUS, NON-INTERSECTION CRASHES

Variable	**Total** N=1675	**No/Minor Injury** N=1510 (90.1%)	**Incapacitating or Fatal Injury** N=165 (9.9%)	**p-value**
Cyclist Characteristics				
Male	1246 (74.4)	1121 (74.2)	125 (75.8)	.9736
Age—mean(SD)	35.2 (22.6)	35.5 (23.0)	33.0 (17.9)	.1785
Under 18	262 (15.6)	234 (15.5)	28 (17.0)	.9243
18–29	644 (38.5)	587 (38.9)	57 (34.6)	.0704
30–49	460 (27.5)	408 (27.0)	52 (31.5)	.5148
50–69	172 (10.3)	151 (10.0)	21 (12.7)	.4446
70 or older	11 (0.7)	6 (0.4)	5 (3.0)	.0002
Unspecified age	126 (7.5)	124 (8.2)	2 (1.2)	.0012
Wearing reflective clothing/light source	506 (30.2)	457 (30.3)	49 (29.7)	.6442
Cyclist Action				
Riding with traffic	853 (50.9)	775 (51.3)	78 (47.3)	.8707
Riding against traffic	143 (8.5)	124 (8.2)	19 (11.5)	.0791
Crossing with signal	36 (2.2)	34 (2.3)	2 (1.2)	.4387
Crossing against signal	19 (1.1)	16 (1.1)	3 (1.8)	.3218
No action	69 (4.1)	65 (4.3)	4 (2.4)	.3107
Enter from driveway	118 (7.0)	110 (7.3)	8 (4.9)	.3342
Turning left	27 (1.6)	27 (1.8)	0 (0)	.0941
Turning right	9 (0.5)	7 (0.5)	2 (1.2)	.1771
Intoxicated/Impaired	9 (0.5)	8 (0.5)	1 (0.6)	.8465
Other action	166 (9.9)	149 (9.9)	17 (10.3)	.9452
Unspecified cyclist action	226 (13.5)	195 (12.9)	31 (18.8)	.0360
Driver Characteristics				
Male	841 (50.2)	766 (50.7)	75 (45.5)	.2079
Age – mean(SD)	41.4 (15.2)	41.6 (15.2)	39.9 (15.3)	.2597
Driver Condition				
Normal	1181 (70.5)	1076 (71.3)	105 (63.6)	.0017
Intoxicated, impaired, or fatigued	11 (0.7)	7 (0.5)	4 (2.4)	.0017
Unspecified driver condition	488 (29.1)	430 (28.5)	58 (35.2)	.1275
Driver Visibility				
Clear visibility	877 (52.4)	794 (52.6)	83 (50.3)	.9526
Visibility obscured by parked vehicle	52 (3.1)	46 (3.1)	6 (3.6)	.6044
Visibility obscured by moving vehicle	34 (2.0)	30 (2.0)	4 (2.4)	.6449
Visibility obscured by other object	70 (4.2)	65 (4.3)	5 (3.0)	.4374
Unspecified driver visibility	646 (38.6)	578 (38.3)	68 (41.2)	.5262
Driver Action				
Failure to yield	440 (26.3)	394 (26.1)	46 (27.9)	.5235
No action	451 (26.9)	406 (26.9)	45 (27.3)	.8205
Disregard traffic control device	3 (0.2)	3 (0.2)	0 (0)	.5693
Driving too fast	16 (1.0)	12 (0.8)	4 (2.4)	.0379
Improper turn	44 (2.6)	41 (2.7)	3 (1.8)	.5083
Following too closely	22 (1.3)	19 (1.3)	3 (1.8)	.5320
Improper lane usage	29 (1.7)	26 (1.7)	3 (1.8)	.9089
Other action	296 (17.7)	272 (18.0)	24 (14.6)	.2859
Unspecified driver action	381 (22.8)	342 (22.7)	39 (23.6)	.7739

Notes: Percent values shown include missing cases in the denominator. P-value for chi-square test including valid responses only. Driver variables may sum to more than 100% because there were multiple drivers involved in some crashes.

Table VI

MOTOR VEHICLE CHARACTERISTICS BY CYCLIST INJURY STATUS, NON-INTERSECTION CRASHES

Variable	Total N=1675	No/Minor Injury N=1510 (90.1%)	Incapacitating or Fatal Injury N=165 (9.9%)	p-value
Type of Motor Vehicle				
Passenger car	1214 (72.5)	1108 (73.4)	106 (64.2)	.0429
Van, sport utility vehicle, or pick-up truck	277 (16.5)	245 (16.2)	32 (19.4)	.2219
Bus	52 (3.1)	45 (3.0)	7 (4.2)	.3345
Truck (single unit or with semi trailer)	27 (1.6)	24 (1.6)	3 (1.8)	.7860
Other type	59 (3.5)	50 (3.3)	9 (5.5)	.1319
Unspecified vehicle type	63 (3.8)	52 (3.4)	11 (6.7)	.0388
Point of Impact				
Front	336 (20.0)	300 (19.9)	36 (21.8)	.5525
Right or left side, center	369 (22.0)	339 (22.5)	30 (18.2)	.2091
Front quarter panel (either side)	507 (30.3)	453 (30.0)	54 (32.7)	.4691
Rear quarter panel (either side)	116 (6.9)	109 (7.2)	7 (4.2)	.1528
Other point of impact	37 (2.2)	30 (2.0)	7 (4.2)	.0539
No impact	35 (2.1)	32 (2.1)	3 (1.8)	.8230
Unspecified point of impact	299 (17.9)	267 (17.7)	32 (19.4)	.5856
Motor Vehicle Maneuver				
Straight ahead	794 (47.4)	709 (47.0)	85 (51.5)	.1704
Left turn	148 (8.8)	131 (8.7)	17 (10.3)	.4386
Right turn	103 (6.2)	99 (6.6)	4 (2.4)	.0392
Slow/stop in traffic (incl. slow turn or loading)	146 (8.7)	131 (8.7)	15 (9.1)	.8035
Enter from driveway or alley	54 (3.2)	51 (3.4)	3 (1.8)	.2956
Passing/overtaking	55 (3.3)	50 (3.3)	5 (3.0)	.8777
Other maneuver*	284 (17.0)	259 (17.2)	25 (15.2)	.5749
Unspecified maneuver	111 (6.6)	97 (6.4)	14 (8.5)	.4095

Note: Percent values shown include missing cases in the denominator. P-value for chi-square test including valid responses only. Motor vehicle variables may sum to more than 100% because there were multiple vehicles involved in some crashes.

There was minimal variation in the distribution of crashes by bike facility and location across years, though some statistically significant differences were found for other crash and environmental conditions (not shown). A greater proportion of crashes occurred during periods of precipitation in 2009 (12.7%) and 2008 (9.4%) compared to 2010 (5.9%, z for trend=-2.66, p=.0077). Slightly more crashes occurred within 100 feet of a bus stop in 2010 (53.6%) than in 2008 (50.8%) and 2009 (48.6%, z=2.18, p=.0291) but differences for the 50-foot indicator were not significant. A smaller share of 2008 crashes occurred near a traffic signal or stop sign (46.7%) compared to the other years (50.1% and 52.7% for a traffic signal/stop sign in 2009 and 2010, respectively, z=3.03, p=.0024). The action of riding against traffic was increasingly frequent among cyclists, from 8.5% in 2008 to 11.8% in 2010 (z=2.63, p=.0009), but other cyclist actions did not vary. Finally, there were no statistically significant differences in cyclist or driver age, sex, or actions by year, except for a marginal increase in the proportion of male cyclists among the 2009 crashes compared to 2008.

4.2 Logistic Regression Results

Results from multivariable logistic regression models for intersection and non-intersection crashes are presented in Tables VII and VIII, respectively. In addition to indicators for the three bicycle facility types (no facility being the reference), the final model for intersection crashes included dummy variables for years 2009 and 2010, daylight at the time of the crash, the MV being a truck, the driver being impaired or intoxicated, the MV making a right turn, the MV slowing or stopping prior to the crash, a rear quarter panel impact to the MV, and the cyclist riding against traffic. For the vehicle type, driver action, MV maneuver, impact points, and cyclist actions, only the specific category(ies) significantly related to injury were retained in the final models, with all remaining categories combined as the reference group. For example, the MV impact location being the rear quarter panel was associated with reduced injury occurrence (adjusted odds ratio, AOR=0.31) compared to all remaining impact locations (front, front quarter panel, side, other) combined. The MV being a truck and the MV driver being impaired were most hazardous for cyclists, with AORs of 5.28 and 6.76, respectively. Cyclists riding against the flow of MV traffic were also at increased risk of injury. There were no differences in the injury outcome for crashes that occurred near a bike lane or a shared lane, but there was a statistically significant protective effect for recommended bike routes at intersections (AOR=0.64, 95% CI 0.42, 0.98, p=.041).

Table VII
MULTIVARIABLE LOGISTIC REGRESSION RESULTS FOR THE RELATIONSHIP BETWEEN CRASH, PERSON, AND VEHICLE COVARIATES AND INCAPACITATING OR FATAL CYCLIST INJURY, INTERSECTION CRASHES

Variable	Categories	Odds Ratio[a] (95% CI)	Adjusted[b] Odds Ratio (95% CI)
Bicycle facility	No facility	-	1.0 (Ref)
	Existing bike lane	1.23 (0.88, 1.74)	0.87 (0.53, 1.44)
	Marked shared lane	1.06 (0.64, 1.77)	0.78 (0.38, 1.60)
	Recommended bike route	0.77 (0.57, 1.03)	0.64 (0.42, 0.98)
Year	2008	-	1.0 (Ref)
	2009	1.43 (1.09, 1.88)	1.43 (0.94, 2.18)
	2010	0.81 (0.61, 1.09)	0.78 (0.49, 1.24)
Light condition	Dusk or nighttime (Ref)	-	1.0(Ref)
	Daylight	0.83, (0.62, 1.10)	0.70 (0.48, 1.02)
Vehicle type	All other vehicles combined	-	1.0 (Ref)
	MV is truck	3.61 (1.71, 7.61)	5.28 (1.86, 14.93)
Driver condition	Normal condition	-	1.0 (Ref)
	Impaired/intoxicated driver	5.11 (1.65, 15.77)	6.76 (1.74, 26.28)
MV maneuver	All other maneuvers combined	-	1.0 (Ref)
	Right turn	0.64 (0.43, 0.96)	0.59 (0.34, 1.00)
	Slow/stop in traffic	0.41 (0.22, 0.75)	0.24 (0.09, .60)
Point of impact	All other points of impact combined	-	1.0 (Ref)
	Rear quarter panel	0.44 (0.18, 1.09)	0.31 (0.09, 1.04)
Cyclist action	All other actions combined	-	1.0 (Ref)
	Riding against traffic	1.47 (0.96, 2.25)	1.72 (1.04, 2.84)

Note: Analysis based on 1,324 observations. CI: Confidence interval.
[a] Unadjusted, from bivariate analysis.
[b] Adjusted for all other covariates listed in the table. Multivariable model Likelihood Ratio χ^2=53.73 (p<.0001), Area under ROC curve= .6740

Interaction terms for the MV type and an impaired driver with the maneuvers included in the model were tested but had no variation with respect to the outcome and were automatically omitted from the model. There were no cases of an impaired truck driver in the sample. Cyclist and driver ages and dummy variables for road type were tested but not significant in intersection crashes when controlling for the other covariates.

The non-intersection crash model included an indicator for the crash occurring in daylight, an impaired or intoxicated driver, a one-way street, dummy variables for categories of cyclist age, and the bicycle facility variables. Daylight and the crash having occurred on a one-way street were protective against incapacitating or fatal injury, while an impaired driver and the cyclist being age 70 or older were associated with increased odds of serious injury. For non-intersection crashes, a bike lane was marginally associated with lower odds of injury (AOR=.55, 95% CI .30, 1.02, p=.058). Recommended bike routes and MSLs were not associated with injury in non-intersection crashes.

Table VIII

MULTIVARIABLE LOGISTIC REGRESSION RESULTS FOR THE RELATIONSHIP BETWEEN CRASH, PERSON, AND VEHICLE COVARIATES AND INCAPACITATING OR FATAL CYCLIST INJURY, NON-INTERSECTION CRASHES

Variable	Categories	Odds Ratio[a] (95% CI)	Adjusted[b] Odds Ratio (95% CI)
Bicycle facility	No facility	-	1.0 (Ref)
	Existing bike lane	0.71 (0.45, 1.10)	0.55 (0.30, 1.02)
	Marked shared lane	0.72 (0.38, 1.35)	0.79 (0.38, 1.62)
	Recommended bike route	1.16 (0.79, 1.70)	0.96 (0.57, 1.63)
Light condition	Dusk or nighttime (Ref)	-	1.0(Ref)
	Daylight	0.57 (0.41, 0.81)	0.63 (0.40, 0.98)
Driver condition	Normal condition	-	1.0 (Ref)
	Impaired/intoxicated driver	5.86 (1.69, 20.33)	4.58 (1.27, 16.51)
Street direction	Two-way street	-	1.0 (Ref)
	One-way street	0.63 (0.37, 1.08)	0.36 (0.16, 0.81)
Cyclist age	Under 18	-	1.0 (Ref)
	18–29	0.73 (0.52, 1.03)	0.66 (0.37, 1.17)
	30–49	1.12 (0.79, 1.59)	0.76 (0.41, 1.40)
	50–69	1.21 (0.74, 1.97)	0.70 (0.33, 1.51)
	70 +	7.28 (2.20, 24.12)	7.42 (1.35, 40.84)

Notes: Analysis based on 1,084 observations. CI: Confidence interval.

[a] Unadjusted, from bivariate analysis.

[b] Adjusted for all other covariates listed in the table. Multivariable model Likelihood Ratio χ^2=29.10 (p=.0012), Area under ROC curve= .6360.

5. DISCUSSION

While the number of police-reported bicycle-MV crashes fluctuated between 2008 and 2010, injury appeared to increase slightly across the three years, particularly non-incapacitating injuries. Given the lack of exposure data (i.e., either cycling frequency of those involved or average ridership for the crash locations) in this study, changes in the true incidence of both crashes and injuries are unknown. It is believed that bicycle ridership has been increasing in Chicago and that more cyclists ride on streets with bike lanes, but clear supporting data are not available. The city of Chicago has made attempts in recent years to assess usage of bikeways to inform decisions about cycling infrastructure improvements. A 2009 pilot study by the Chicago Department of Transportation (CDOT) involved taking 24-hour counts of cyclists at 29 on-road locations throughout the city of Chicago during select months between May and November.[56] All but two of those locations had either an existing bike lane or a MSL; the two untreated streets observed had very low cyclist counts but the study was not designed for comparisons based on facility presence. Ongoing bike counts have been conducted in the downtown area by CDOT, including monthly counts at six locations in central parts of the city in January 2012. However, all locations have a bicycle facility and none of the 2009 study locations were selected for the monthly counts, precluding a bicyclist count comparison between the studies. One-year estimates from the ACS suggest a slight increase in commuting by bicycle among Chicagoans: in 2008 1% (+/- 0.2%) of city commuters reported a bicycle as the primary mode of transport compared to 1.4% (+/- 0.2%) in 2011.[57] If more cyclists are on the roads each year, there may have been slight declines in reported crash and injury incidence, as suggested by Chen et al. in the New York City study.[58] As CDOT has installed new bike lanes, ridership on those streets may have increased in particular. In Teschke's Canadian case-crossover study, median cyclist counts were higher on roads with bike lanes than untreated streets.[59] In this current study, 705 of 4,031 bike-MV crashes occurred on or near streets with a bike lane (17.5%) and 317 (7.9%) were on streets with a MSL. If just half of cyclists are riding primarily on streets with designated bike lanes or MSLs then crash incidence may be much lower on these streets than on untreated roads.

This study offers some limited evidence of potential associations between bicycle facilities and cyclist injury. At intersections, crashes at recommended bike routes were significantly less likely to result in an incapacitating or fatal injury to the cyclist compared to crashes at untreated intersections. Given that bike routes in Chicago include street-side signage but no designated space for cyclists or pavement markings on the road itself, it may be that cyclist visibility and signage alerting drivers to the presence of cyclists on these roads play a role in traffic crashes. How this translates to a reduction in incapacitating or fatal injury requires further investigation. In non-intersection crashes, the presence of an existing bike lane was associated with lower odds of incapacitating or fatal cyclist injury (of marginal significance) compared to untreated roadways. Bike lanes are designated with pavement striping and other markers and sometimes also street-side signage, which increases the visibility of cyclists and alerts drivers to their potential presence. Bike lanes also serve to provide cyclists with a distinct portion of the roadway on which to travel, separate from MV traffic. It is possible that the physical distance between MVs and cyclists prior to a mid-block crash allows for avoidance maneuvers and preventive action that mitigates injury to the cyclist. Overall, crashes on collector streets were more likely to have a bicycle facility than were crashes on arterial or local roads. The lower traffic on a collector road might offer a safer alternative for cyclists than traveling on busier arterials; however, when a dummy variable for collector streets was tested in the regression models it was not significant.

Caution should be taken in interpreting the results from the multivariable analyses. Model fit statistics, such as the area under the ROC curve, suggest that the models for both intersection and non-intersection crashes did not fully explain the injury outcome data. These models were selected with the principle of parsimony in mind as well as adequate adjustment for potential confounding variables.

However, the model fit statistics suggest that the remaining unexplained variation in the data may be due to variables not available for the analysis. Additionally, list-wise deletion of observations due to excessive missing data may have affected the final models and account for some of the differences between the unadjusted and adjusted estimates, beyond the differences that would be expected from adjustment for the other covariates in the models. Multiple imputation and alternative modeling approaches might address some of these issues.

With respect to crash location relative to an intersection, different factors were associated with odds of incapacitating or fatal injury. Motor vehicle factors and cyclist actions were important in intersection crashes but not non-intersection crashes. In non-intersection crashes, one-way street direction was protective, suggesting that cyclist visibility mid-block is important. Drivers on a one-way street do not have to focus on oncoming traffic and so may be better able to focus on the presence of cyclists than on two-way streets. When controlling for other factors, cyclist age was associated with injury only in non-intersection crashes, but only cyclists over 70 were at greater risk of incapacitating or fatal injury. Other studies have also found older adults to be at greater risk for serious injury in bicycle crashes.[60,61,62] An intoxicated or impaired driver posed a significant hazard to cyclists in both intersection and non-intersection crashes, even though counts of these cases were small in this study. A crash occurring in daylight was protective against injury for both types of crashes. These findings by crash location are generally consistent with those of a similar study by Moore et al., who examined the Ohio crash report data stratified by location. In that study, mixed logit models of injury as a categorical variable identified cyclist helmet use, an intoxicated motorist, a side impact, and the MV being a van as important predictors of severe injuries in intersection crashes, and a cyclist under the influence of drugs, an intoxicated motorist, a side impact, and heavy-duty trucks were associated with severe injury for non-intersection crashes. In this analysis of IDOT data, cyclist intoxication was not associated with injury severity. Because there were too few valid responses for the helmet-use variable in the IDOT data, this factor could not be included in the models. A side impact was not associated with serious or fatal injury in this analysis, though a rear quarter panel impact was marginally protective in an intersection crash.

Kim and colleagues analyzed police-reported crash data in North Carolina and found that a turning or merging MV and a two-way divided road increased risk of non-incapacitating injury, while a heavy truck, intoxicated driver, and curved road were associated with incapacitating injury.[63] The MV being a pickup truck and various vehicle speeds were positively associated with both types of injury and a cyclist riding facing traffic was negatively associated with both types. The findings regarding a turning MV, an intoxicated/impaired driver, and heavy trucks are consistent with the present study, but one-way roads were protective against serious or fatal injury in the IDOT data and associated with a higher proportion of non-injury or minor injury cases. Divided and undivided two-way roads were combined in this study, so those results cannot be directly compared with those of Kim et al.

Missing data and unmeasured variables are a limitation of this analysis because some factors that have been identified as important in previous research and may have been associated with the injury outcome in Chicago crashes were not included in the models. As previously mentioned, cyclist helmet use was unaccounted for. It is important for police to be trained to record the cyclist's helmet use, as this is a very important factor for bicycle-MV crashes. Additionally, the cyclist action and driver condition variables suggested that few crashes involved intoxicated drivers or cyclists, but these may also be underestimates. In the Ohio study, nearly one-third of the cyclists were wearing a helmet, 1.9% had consumed alcohol, while 1% of the drivers had consumed alcohol. In the North Carolina study, 6% of the cyclists wore a helmet, 5.9% were coded as intoxicated, and 2.3% of the drivers were intoxicated. In the IDOT data, 0.8% of cyclists wore a helmet (assuming those missing data did not) and 0.6% of cyclists and 0.8% of drivers were intoxicated or impaired. Motor vehicle speed has also been identified as a critical factor affecting injury in traffic crashes. Vehicle speed was not included on the IDOT file, but only

1% of the crashes were reported to involve a driver going too fast. However, in the bivariate analyses, a speeding driver was positively associated with the injury outcome, though the relationship did not hold in the multivariable models. Speed limit for the streets containing a crash point was not included in the analysis because there is little variation in speed limits in Chicago; most roads have a speed limit of 30 mph. Last, a GIS file for street parking throughout the city was not available to include in this study. The presence of MVs parked parallel to the curb may have some effect on the types of crashes that occur in non-intersection locations.

Crash report data, typically collected by police and compiled by state departments of transportation, have been used in numerous studies to identify risk factors for crashes and to investigate injury in bicyclist crashes both in the United States[64,65,66,67,68] and elsewhere.[69,70,71] The benefits of police data include the range of variables provided, such as cause of the crash, roadway conditions, and numerous driver, cyclist, and vehicle characteristics that are not present in hospital or emergency department data. These factors allow for control of important covariates. However, the limitations of police-report data have been well documented, particularly police injury assessments. Crash reports attempt to characterize injury severity but typically do not include information on the nature of injuries or the regions of the body that are affected. Moreover, studies attempting to test reliability of police injury-coding suggest that it does not correlate well with injury scales such as the Injury Severity Scale or the Abbreviated Injury Scale (AIS), which use more detailed medical information such as from hospital records. A California study that compared highway patrol data and a hospital monitoring system in Orange County for pedestrians and cyclists under age 15 showed that police underreported serious injuries, coding various leg and skull fractures that had an AIS score greater than nine under the “complaint of pain” category that is akin to “possible injuries” in the IDOT data.[72] In a 1993 Australian study, Rosman and Knuiman linked crash reports to hospital data and also found police injury-coding to be unreliable.[73] Farmer compared police report data with in-depth investigations from the National Automotive Sampling System, validating police injury codes against the AIS, finding that nearly half of police-coded incapacitating injuries were actually only minor injuries (Maximum Abbreviated Injury Scale of 1), and there was differential misclassification of severity by census region, time of the crash (daytime versus nighttime), driver gender, manner of collision, and driver age.[74] Rosman and Knuiman suggest that crashes that result in more severe injuries are more likely to be reported to police. Property damage-only crashes, or collisions that result in no damage or injury, appear to be the least likely to be reported to police. A Canadian survey of cyclists involved in collisions or falls showed that only between 10% and 20% of the cyclists reported the incident to police.[75]

A strength of this study is the examination of different bicycle facilities, which has been identified as lacking in earlier literature.[76] Future studies of bicycle facilities in Chicago should also include physically separated bicycle lanes, which have become a priority infrastructure improvement in recent years. None were installed before or during the study period. Another contribution of this study is the exploratory examination of bus stops and their proximity to bike-MV crashes. Public transit buses can represent an obstacle for cyclists, who must often weave around them at intersections in order to maintain efficient rides. This type of maneuver puts cyclists in the path of other MVs traveling in the same direction, which could potentially increase bike-MV conflicts and crash risk. No association between bus stop location and injury was found among the IDOT crashes. Future research should continue to examine the role of transit stops or stations and transit vehicles and in bike-MV crashes, even when the transit vehicles themselves do not collide with a cyclist.

This analysis also has some additional limitations that should be noted. First, misclassification is possible with respect to the primary bike infrastructure measures and bus stop variables. Because some intersections would have a bike lane, shared lane, or bike route on only one of the intersecting streets, the bike facility data would have linked to all crashes at that intersection even if the cyclist was riding on a street without the facility. Similarly, a bus stop on any corner of an intersection would be associated with a crash there. Such error should be random and unlikely to introduce any particular bias with respect to the injury outcome measure. A larger percentage of non-intersection crashes were associated with a bike lane or shared lane compared to the intersection crashes, whereas recommended bike routes, similar to untreated roads, were linked to more intersection crashes using this method. Additionally, the precise date of facility installation was not available for this analysis. If any date was included at all, it was the year of installation. The method used to assign the date for facilities that were installed during the study period, which was a mid-year installation date of July 1, is unlikely to introduce bias in exposure assignment and any temporal error in the bike facility designation should be random.

Finally, with respect to the IDOT data coverage, there is a potential difference in completeness by crash location relative to an intersection. For cyclists riding along a roadway segment not adjacent to an intersection, one of the most common collision risks is the opening of a parked car door, known as "dooring." These incidents have historically not been included in the IDOT data given that they do not involve a moving MV. Therefore, non-intersection crashes may be underrepresented in this analysis, although IDOT began including some dooring cases in 2009. Severe injury or fatality can result from such incidents, but it is not known whether the presence of a bike lane or shared lane increases risk of these collisions.

6. CONCLUSIONS

On-road bicycle facilities have been shown to be valued and utilized by cyclists when they are available, and there is a general public perception that they offer a safer alternative to cyclists compared to untreated roads. To date, few studies have examined the relationship between different bicycle facilities and cyclist injury outcomes, particularly in the United States. Results from this analysis suggest that designated bike lanes may confer a protective effect against incapacitating or fatal injury in non-intersection bicycle-MV crashes. However, the observed relationship did not reach statistical significance when controlling for other factors and thus more research is needed to confirm that such a protective effect truly exists. Reduced frequency of incapacitating or fatal injury was observed in intersection crashes that occurred on or near a recommended bike route and the relationship was statistically significant after controlling for other factors. Due to the exclusion of some important variables (e.g., cyclist helmet use, MV speed), these results must be interpreted with caution.

Beyond ridership and utilization, policy makers and transportation officials need reliable data on road safety for cyclists. Given the limitations of police report data, multiple sources of information are needed to provide a clear picture of cyclist accident patterns and the safety of different infrastructure types. Linkage between police report data and hospitalization data through emergency department records or the Illinois Trauma Registry, such as the NHTSA-sponsored Crash Outcome Data Evaluation System, would be best suited to identify the relationship between infrastructure and injury severity. Additionally, surveys of cyclists could provide additional information on other characteristics of those involved in crashes with MVs, such as cycling experience, knowledge of traffic laws, and whether collisions they were involved in were reported to the police. As more cyclists take to the road and scarce transportation dollars are allocated to infrastructure improvements, identifying the safest approaches to road design for all users will remain important in order to reduce cyclist injury and the associated costs.

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